Renewable and Sustainable Energy Reviews 15 (2011) 404–415

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A comprehensive review of biomass resources and biofuels potential in Ghana

Moses Hensley Duku [a,b], Sai Gu [a,*], Essel Ben Hagan [b]

[a] School of Engineering Sciences, University of Southampton, Southampton, S017 1BJ, UK
[b] Institute of Industrial Research, Council for Scientific and Industrial Research, P. Box LG 576, Legon, Ghana

ARTICLE INFO

Article history:
Received 31 August 2010
Accepted 9 September 2010

Keywords:
Biomass
Agricultural residues
Forestry residues
Feedstock
Biofuel
Lignocellulose

ABSTRACT

Biomass is the major energy source in Ghana contributing about 64% of Ghana's primary energy supply. In this paper, an assessment of biomass resources and biofuels production potential in Ghana is given. The broad areas of energy crops, agricultural crop residues, forest products residues, urban wastes and animal wastes are included. Animal wastes are limited to those produced by domesticated livestock. Agricultural residues included those generated from sugarcane, maize, rice, cocoa, oil palm, coconut, sorghum and millet processing. The urban category is subdivided into municipal solid waste, food waste, sewage sludge or bio-solids and waste grease. The availability of these types of biomass, together with a brief description of possible biomass conversion routes, sustainability measures, and current research and development activities in Ghana is given. It is concluded that a large availability of biomass in Ghana gives a great potential for biofuels production from these biomass resources.

Contents

* Corresponding author. Tel.: +44 02380598520; fax: +44 02380593230.
E-mail address: S.Gu@soton.ac.uk (S. Gu).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.09.033

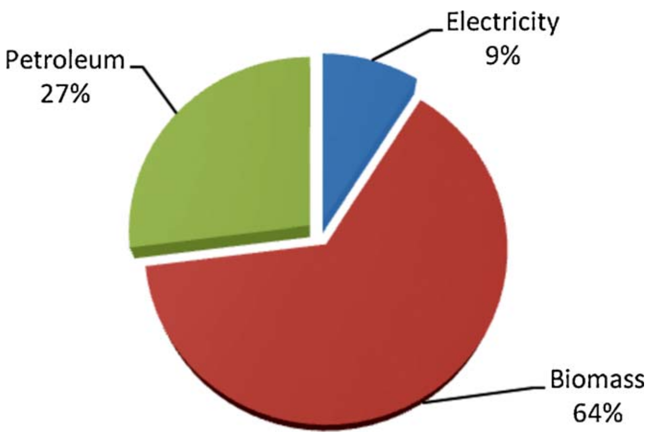

Fig. 1. Energy balance in Ghana in 2007 (total = 9.50 Mtoe) [6].

1. Introduction

Biomass is becoming increasingly important globally as a clean alternative source of energy to fossil fuel as a result of rising energy demand, high cost of fossil fuels, dwindling fossil fuel reserves and contribution of fossil fuel usage to greenhouse effect. In Ghana, the primary energy supply is based on biomass, mainly firewood and charcoal (64%), petroleum (27%), and electricity (9%) (Fig. 1). Electricity generation is from two hydro-electric power plants and a thermal plant [1–3]. Currently, the country is dependent entirely on imports for oil requirements, but it has an oil refinery with a capacity of 45,000 barrels of oil per day [4]. However, in 2007, a major fossil fuel discovery was made in the country which has the potential to reduce the dependence on imported oil. The transport sector consumes around 78% of annual consumption of petroleum products, which consists mainly of gas oil (diesel), gasoline, kerosene, and liquefied gas. With the completion of the West African Gas Pipeline project, it is expected that Ghana and other countries such as Benin and Togo would be provided with natural gas from Nigeria [5,6].

The country's total land area of 23,853,900 ha is divided into ten administrative regions. Approximately 14,850,000 ha of the total land area are classified as an agricultural land area, of which arable land constitutes 28% and permanent crops 16%. In 2008, the population of the country was estimated at 23.351 million inhabitants, with a growth rate of 2.0% per annum. Gross domestic product (GDP) was US$7.20 billion in 2007 (Table 1) [7]. About 68% of the country's population live in rural areas. The domestic economy revolves around agriculture, which accounted for about 37% of GDP and employed about 57% of the work force, mainly small landholders in 2005.

The industrial sector accounts for about 25% of GDP. Gold and cocoa are the major sources of foreign exchange. Other major industrial activities are food, timber, oil refining, textiles, vehicles, cement, paper, chemicals, soap, beverages, rubber, aluminium, and pharmaceuticals [8–11]. Poverty trends in Ghana differ among the various economic sectors. Poverty is particularly evident in two sectors: agriculture and the informal sector, with the agricultural sector being the worse affected. Next to agriculture, 29% of those in micro and small enterprises live below the poverty line. The United Nations Development Programme (UNDP) has reported that food crop farmers are the poorest compared to people in other activities [12–14].

Table 1
General population information and economic indices [11–13].

Parameter	Unit	Value	Year
Population	Million	23.351	2008
Population growth rate	%	2.0	2008
GDP	Billion USD	7.20	2007
GDP real growth rate	%	7.30	2008
GDP per capita (PPP)	USD	55.23	2007
Poverty rate	% total population	28.50	2007
HDI	–	0.526	2007
TPES	Mtoe	9.50	2007
Net Energy Imports	Mtoe	3.15	2007
CO_2 emission	Mt of CO_2	9.00	2007
Energy production	Mtoe	6.47	2007

Table 2
Consumption of wood fuel and wood charcoal in Ghana, 2004–2008 [9].

Year	Wood fuel (m^3)	Wood charcoal (tonnes)
2004	20,678,000	752,000
2005	20,678,000	752,000
2006	33,039,530	1,358,977
2007	31,477,900	1,418,300
2008	35,363,400	1,477,700
Total	141,236,830	5,758,977

Recently, energy demand in the country has increased significantly as a result of population increase and urbanisation. The increased demand is, however, more pronounced in the consumption of wood fuel, particularly wood charcoal. According to the Food and Agriculture Organisation of the United Nations (FAO) Statistics [9], the consumption of woodfuel increased from 20.6 million m^3 in 2004 to 35.4 million m^3 in 2008, while the consumption of wood charcoal also increased from 752,000 m^3 to 1.48 million m^3 during the same period (Table 2). Traditional wood energy systems rely on low-cost technologies affordable to low income consumers. Access to modern biomass is limited, resulting in the huge dependence on primary biomass as a source of energy which has been observed to be a major factor in the rapid deforestation, land degradation and related health problems in the country. The use of biofuels derived from a renewable resource as both a domestic and transport fuel, and also for stationary engines can have significant environmental benefits in terms of decreased global warming impacts, reduced fossil CO_2 emissions, reduced fossil fuel dependence and rural development, while it also has a low sulphur and nitrogen content. But, there is, currently, inadequate information available to enable any meaningful policy to be based on for the development and implementation of biofuel projects in Ghana.

The objective of this paper is to review biomass resources availability and biofuels potential in the country. Here, we have attempted to assess the various biomass types available for biofuel production using current biomass conversion routes, particularly, first- and second-generation technologies. The information resulting from this study will serve as a base for further, more detailed site-specific biomass assessments.

2. Biomass resources in Ghana

Biomass is a term used for all organic matter that is derived from plants as well as animals. Biomass resources include wood and wood wastes, agricultural crops and their waste by-products, municipal solid waste, animal wastes, wastes from food processing, aquatic plants and algae [15]. There are competing uses for these resources because of their economic and environmental value. Biomass can be used to generate power, heat and steam, and for the production of transportation fuels. It is also used by the food processing, animal feed, and the wood processing industries [16].

Biomass is composed mainly of cellulose, hemicellulose, lignin, and small amounts of extractives. The suitability of a particular biomass as a potential feedstock for biofuels production depends

on various characteristics such as moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen, volatiles, ash content, and cellulose/lignin ratio. Generally, cellulose is the largest fraction, and constitutes about 38–50% of the biomass by weight. Cellulose is a polymer of glucose, consisting of linear chains of (1,4)-D-glucopyranose units with an average molecular weight of around 100,000. It is the most abundant form of carbon in the biosphere, and is a good biochemical feedstock [17]. Hemicellulose, on the other hand, is a polymer of 5-carbon mainly xylose, and 6-carbon monosaccharides. Xylose is the second most abundant sugar in the biosphere. Unlike cellulose, hemicellulose is a marginal biochemical feedstock. It represents 20–40% of the material by weight.

Lignin can be regarded as a group of amorphous, high molecular-weight, chemically related compounds. The building blocks of lignin are believed to be a three carbon chain attached to rings of six carbon atoms, called phenyl–propane. Lignin constitutes about 15–25% of the composition of lignocellulosic biomass. It has very high energy content, and also resists biochemical conversion [17]. The term biofuel, according to the FAO [18], is increasingly being used to refer specifically to liquid or gas fuel derived from biomass. Liquid biofuels can be classified into first-generation and second-generation biofuels. First-generation biofuels are defined as biofuels which are on the market in considerable amounts currently. They are generally made from sugars, grains or seeds using only a specific, often edible part of the above ground biomass. Typical first-generation biofuels are sugarcane ethanol, starch-based or corn ethanol, biodiesel, and pure plant oil (PPO). Bioethanol is the dominant liquid biofuel currently, representing approximately 85% of the global biofuel production, while biodiesel accounts for the other 15%. Second-generation biofuel is generally made from lignocellulosic biomass, also called cellulosic biomass [19].

2.1. Agricultural resources in Ghana

Ghana's agricultural sector is characterised by a large number of dispersed small-scale producers, employing manual cultivation techniques dependent on rain-fed with little or no purchased inputs but provide over 90% of the food needs of the country. Farming systems vary with the six agro-ecological zones [Table 3]. However, certain general features are discernible throughout the country. According to the World Trade Organisation (WTO) [10], crop production in Ghana is hampered by land degradation, improper field development, use of low-yield varieties, lack of organised seed production and distribution systems, and inadequate storage structures. Major crops cultivated include maize, rice, sorghum, cassava, yams, plantain, groundnuts, cowpeas, cocoa, oil palm and coffee. Aside from the commercial plantations such as cocoa, rubber, palm oil, and coconut production, and to a lesser extent, rice, maize and pineapples, about 90% of farms in the country are less than 2 ha in size [22].

2.1.1. Energy crops (woody energy crops and perennial herbaceous crops)

In Ghana, energy crops that have potential as feedstocks for biofuel production include sugarcane, sweet sorghum, maize and cassava for ethanol, and oil palm, coconut, sunflower, soy bean and jatropha for biodiesel [4]. The key characteristics of major energy crops in the country, together with production data for 2008 are presented in Tables 4 and 5, respectively.

- Corn/maize

  Currently, ethanol for transportation is produced mostly from sugarcane in Brazil, and maize in the USA. About 25 million ha of land are used for maize cultivation in sub-Saharan Africa. South Africa, Nigeria, Ethiopia, Kenya and Tanzania are reported to be the main sugarcane producers [21]. Maize is grown in all the agro-ecological zones in Ghana. Approximately 1.10 million - tonnes of maize were harvested from an area of 750,000 ha in 2008 [22].
- Cassava

  Cassava is an important staple crop in Ghana. In 2008, approximately 9.65 million tonnes of the crop were harvested from an area of 800,000 ha. The FAO Statistics [22] for crop production show that there was a significant increase in cassava production from 2001 to 2008. The increase has been attributed partly to the introduction of high-yielding new varieties, and the President's Special Initiative on cassava production.
- Sugarcane

  Sugarcane production in the country increased slightly from 140,000 tonnes in 2000 to 145,000 tonnes in 2008. In comparison with cassava and maize, sugarcane production is relatively low. However, it is reported that there are efforts being made to revitalise the sugarcane industry [23].
- Sweet sorghum

  Sweet sorghum is increasingly gaining importance as a potential feedstock for bioethanol production. The grains are traditionally used as a food crop, while the stalk makes an excellent fodder. The high sugar content of the stalk makes the crop an attractive feedstock for biofuel production. It is reported that approximately 25 million ha of land are under sorghum cultivation in sub-Saharan Africa, with Nigeria, accounting for about 39% of total production, followed by Sudan, Ethiopia, and Burkina Faso [21]. In Ghana, sweet sorghum is cultivated mainly in the savannah zones. In 2008, the FAO crop statistics showed that approximately 350,000 tonnes of sorghum were produced from an area of 340,000 ha in the country [22].
- *Jatropha curcas*

  Jatropha curcas plantations in the county cover over 1,534 ha. Traditionally, the plant has been used as a fence around homesteads and gardens because it is not browsed by animals; the fruits and seeds are not edible. Garwe et al. [25] reported that jatropha has a short establishment period which ranges between 2 and 5 years, and a longevity of up to 50 years. Jatropha plant has the ability to grow on degraded soils. Its cultivation is also characterised by low cost of production, and low nutrient

Table 3
Agro-ecological zones of Ghana [8,20].

Zones	Area (1000 ha)	Portion of total area (%)	Mean annual rainfall (mm)	Growing period (days)		Main food crops
				Major season	Minor season	
Rain forest	750	3	2,200	150–160	100	Roots, plantain
Deciduous forest	740	3	1,500	150–160	90	Roots, plantain
Transition	6,630	28	1,300	200–220	60	Maize, roots, plantain
Guinea savannah	14,790	63	1,100	180–200		Sorghum, maize
Sudan savannah	190	1	1,000	150–160	–	Millet, sorghum, cowpea
Coastal savannah	580	2	800	100–110	60	Roots, maize

Table 4
Summary of key characteristics of first-generation biofuels feedstock [21].

Optimal growing conditions	Ethanol yields (l/ha)	Preferential rainfall (mm/year)	Sensitivity top water supply	Fertiliser	Pesticide use
Ethanol					
Sugarcane	4,000–8,000	1,500–2,500	High	High	Medium
Maize	700–3,000	700–1,500	High	Medium	High
Sweet sorghum	3,000–6,000	400–650	Low to medium	Medium	High
Cassava	1,750–5,400	1000–1,500	Low to medium	Low to medium	Medium
Biodiesel					
Palm oil	2,500–6,000	1,800–2,500	High	Low	Low
Jatropha	400–2,200	600–1,200	Low to medium	Low	Low

requirement. Jatropha is cultivated and processed at various scales such as micro or subsistence, community farming and commercial levels. According to the World Bank, a total of seventeen (17) commercial biofuel developments have been identified in the country [26]. Table 5 shows some of the major stakeholders in the cultivation and utilisation of *Jatropha curcas* in Ghana.

The Ghana Government's interest in promoting the cultivation and use of jatropha for biodiesel production is based on the plant's ability to grow in a wide range of environments, and also the potential to create jobs for a large number of people [4]. Jatropha oil is utilised to power multi-functional platforms (MFPs) driven by diesel engines, mostly by women for the improvement of their livelihoods. The oil is also used for income-generating activities such as soap making in rural communities, mostly in some rural communities in the three northern regions. The seed cake resulting from processing of the seed has been found to contain a high mineral content, and thus can be used as an organic fertiliser. It could also be used as feedstock for second-generation biofuels production [Table 6].

- Oil palm

In Africa, the oil palm tree (*Ela*eis *guineensis*) is mostly cultivated in Central Africa and parts of West Africa. Nigeria is the largest producer of palm oil, with a global market share of 3%, followed by la Cote d'Ivoire, and the Democratic Republic of Congo, both having a market share of around 0.5% [21]. Production of oil palm fruits in Ghana increased from 1.1 million tonnes in 2001 to 1.9 million tonnes in 2008 [22]. Oil palm plantations in the country cover approximately 320,000 ha, and are located mostly in the rain forest and deciduous zones of the Ashanti, Western, and Eastern regions [10]. Generally, oil palm cultivation is carried out on varying scales such as smallholder farms, and medium-to large-scale plantations [Table 7].

As part of the Government's strategy to improve the oil palm industry in the country, a Presidential Special Initiative (PSI) on Palm Oil Plantation and Exports was launched around 2004. So far, about US$3.4 million have been invested in the initiative. Under the programme, about 100,000 ha of oil palm plantations were planned to be cultivated over a 5-year period in six regions in the country, together with the establishment of 12 nurseries to raise about 1.2 million high-yielding seedlings for supply to farmers. The Oil Palm Research Institute (OPRI) of the CSIR (Council for Scientific and Industrial Research) has been given the task to produce two million high-yielding seedlings annually [27]. Table 7 shows major stakeholders in the oil palm industry.

- Other plants

Coconut plantations in Ghana cover an area of about 30,000 ha, and have average yields of about 5,000 nuts per ha [10]. However, about 4,000 ha of these plantations mainly in the coastal belt have been affected by the Cape Saint Paul Wilt Disease, a lethal yellowing disease. Between 1990 and 2005, the Government implemented a Coconut Sector Development Project which resulted in the rehabilitation of approximately 800 ha of coconut farms. In addition, the CSIR has developed a coconut hybrid to replace the affected trees [28–30].

Sunflower is gaining importance in the country as potential biofuel feedstock. Generally, the cultivation of sunflower seeds is based predominantly on smallholder farms. Recently, under a project funded jointly by the Global Environment Facility/Small Grant Project (GEF/SGP) and the United Nations Development Programme (UNDP), approximately 230 ha of sunflower farms have been established in the country [31]. Annual production of soybean in Ghana amounts to 50,000 tonnes, with only 15,000 tonnes being utilised locally [32]. Cultivation of soybean is concentrated mainly in the Northern, Upper East and Upper regions. The mean acreage per farmer is about 1.38 ha. In the

Table 5
Production of major crops in Ghana 2008 [22].

Product	Production (1,000 tonnes)	Yield of crop (Hg/ha)	Area harvested (ha)
Sorghum	350	10,294	340,000
Maize	1,100	104,615	750,000
Sugarcane	145	2,544,385	5,700
Rice	242	20,166	120,000
Cocoa beans	700	4000	1,750,000
Coffee, green	1.6	1650	10,000
Cassava	9,650	120,625	800,000
Seed cotton	2	8,000	25,000
Soya beans	n.a	n.a	n.a
Coconuts	316	56,936	55,500
Oil palm fruits	1,900	6,333	300,000
Ground nuts	4,289	9,317	460,000

Table 6
Major investments in *Jatropha curcas* plantations in Ghana [24].

Name of institution/company	Land area under cultivation (ha)	Funding sources
B1 Ghana	700	Private investment
ADRA/UNDP	800	UNDP/GEF/ADRA
New Energy	6	Donor funding
Gbimisi Women Group	4	UNIFEM/UNDP-GEF
AngloGold Ashanti Ltd	20	Corporate Fund
Valley View University	4	University Funds
Total	1534	

Table 7
Major investments in the oil palm industry in Ghana [27].

Company	Location
Benso Oil Palm Plantation (BOPP) Ltd.	Benso
Twifo Oil Palm Plantation (TOPP) Ltd.	Twifo Praso
Ghana Oil Palm Development Corporation Ltd. (GOPDC); known as the Okumaning Oil Palm Plantation Development Programme	Akim Oda
National Oil Palm Plantation	New Juaben
Norpalm Ghana Ltd. (formerly called Prestea Oil Palm Plantation)	Prestea
National Oil Palm Plantation Ltd.	Ayiem

southern sector of the country, production is still at the rudimentary stages, except for Ejura Farms Limited which has cultivated about 121.4 ha, and a few satellite farmers [33].

- Grasses

  Many of the grass species that have been used as hay and pasture for livestock feed or for soil conservation may be used as energy crops. In Ghana, potential exists for the utilisation of various grass species, including *Pennisetum purpureum* (elephant grass), *Panicum maximum* (guinea grass), *Panicum virgatum* and *Miscanthus giganteus* as feedstock for biofuel production. Currently, these resources are underutilised. Grasses have high fiber (cellulose, hemicellulose, and lignin) content, and can be converted into energy by a variety biomass conversion methods including direct combustion for heat and/or power, cellulosic conversion to ethanol, thermochemical processes for fuel supplements and anaerobic digestion for methane. According to a report by Scurlock [34], miscanthus has relatively high yields of 8–15 tonnes/ha dry weight, low moisture content, low mineral content, a good energy balance and output/input ratio compared with some other biomass options. It also tolerates brackish water, and uses a minimum amount of nutrients from the soil.

- Algae

  Algae are organisms that grow in various aquatic environments. There are two categories of algae: macroalgae and microalgae. Macroalgae are the large multi-cellular algae often seen growing in ponds, known as seaweeds. Microalgae, on the other hand, are tiny, unicellular algae that normally grow in suspension within water-bodies. They represent a highly specialized group of micro-organisms that live in diverse ecological habitats such as freshwater, brackish, marine and hyper-saline, with a range of temperatures and pH, and unique nutrient availabilities. They are classified into major groupings including cyanobacteria, green algae, diatoms, yellow-green algae, golden algae, red algae Algal biomass consists of three main components: carbohydrates, proteins, and lipids/natural oils. Many algal species have been found to grow rapidly and produce substantial amounts of triglycerides (TAGs) or oil, and are thus referred to as oleaginous algae [35,36].

Recently, the use of microalgae as an alternative biodiesel feedstock has gained renewed interest from researchers, entrepreneurs, and the general public. It is reported that microalgae could be cultivated in an aquatic environment for the production of triglycerides, which could then be used to produce oil algae, a third generation-biofuel [19]. The technology for conversion of triglycerides produced by algae is similar to that for the first-generation biodiesel production. One advantage of using algae biomass for biodiesel production is the potential mitigation of CO_2 emissions from power plants. Studies on phytoplankton in some Ghanaian lagoons and estuaries indicated that cynobacteria comprise either the highest or the second highest component of the phytoplankton biomass. In addition, various macro-algae including, Chlorophyta, Phaeophyta and Rhodophyta species have been identified to be usually attached to rock surfaces in the inter-tidal and sub-tidal areas [36]. Thus, research into the utilisation of algae could provide environmentally friendly solutions to both global and national threats, like GHG emissions. Algae fuel, also called algal fuel, algaeoleum or second-generation biofuel, is a biofuel which is derived from algae [36].

2.2. Agricultural crop residues

Agricultural crop residues are classified into crop residues and agricultural industrial by-products [26]. Crop residues are the materials left on the farms after harvesting the target crops or burnt on the farms. Crop residues in Ghana include straw, and stalk of cereals such as rice, maize/corn, sorghum, and millet, and cocoa pods. Agro-industrial by-products, on the other hand, are produced mainly after crop processing, and include cocoa husk, coconut shell and husk, rice husk, oil seed cakes, sugar cane bagasse, and oil palm empty fruit bunch (EFB). Table 8 shows the major agricultural crop residues and by-products generated in the country, based on 2008 crop production data [22], using residue-to-product ratios (RPRs) [37,38]. These residues have a high potential for energy production.

Cocoa makes a very important contribution to the economy of the country. It is the dominant cash crop and the single most important export product in Ghana [10]. Cocoa production occurs in the forested areas, namely Western, Ashanti, Brong-Ahafo, Central, Eastern region, and Volta Regions, and covers roughly 1.75 million ha. At the moment, cocoa pods are left on the farms to mulch, while some of the husk is exported [39–43]. In comparison with cocoa, coffee plantations cover only a total area of approximately 10,000 ha, and coffee production has been relatively low. The husk, which is the main residue generated during processing using the dry method, can be utilised as an organic fertiliser. Also, when compressed, it can be used for power generation [15,41–45]. Major residues generated from harvesting and processing of maize are the stalk, cob and husk which are also potential biofuel feedstock. Similarly, the stalk of sweet sorghum, which is rich in sugar, is a potential feedstock for ethanol production.

Oil palm plantations cover roughly 300,000 ha. There are three main residues, namely, empty fruit bunches (EFB), shells and fronds. These residues, however, have competing uses, particularly, the EFBs, which are rich in potassium, since they can be used as a

Table 8
Production of different agricultural crops in Ghana for 2008 and estimated potential of residues, calculated using residue to product ratio [19,22] and lower heating value (LHV) [15].

Crop[a]	Production ($\times 10^3$ tonnes)	Residue type	Residue to product ratio (RPR)[b]	Moisture content (%)	Residue (wet tonnes)	Residue (dry, 10^3 tonnes)	Lower heating value (MJ/kg)	Residues energy potential (TJ)
Sorghum	350	Stalk	2.62	15	917.00	779.45	17.00	15.59
Millet	160	Stalk	3	15	480.00	408.00	15.51	7.44
Rice	242	Straw	1.5	15	363.00	308.55	15.56	5.65
Sugarcane	145	Bagasse	0.3	75	43.50	10.875	13.38	0.58
Coconut	316	Shell	0.6	10	189.6	170.64	10.61	2.01
Oil palm fruits	1,900	EFB	0.25	60	4750	190.00	15.51	7.37
Coffee	165	Husk	2.1	15	346.50	294.525	12.56	0.04
Cocoa	700	pods, husk	1	15	700.00	595.00	15.48	10.84
Maize	1,100	stalk	1.5	15	1650.00	1402.50	15.48	25.76
Total					4821.6			75.20

[a] Crop production is based on [22].
[b] Estimated yield calculated based on RPR sourced from [19].

fertiliser, and the shells for production of activated carbon and heating, while the fronds are usually used for mulching. The residues of coconut, mainly the husk and shells are also potential sources of energy. The three main residues generated through the harvesting and processing of sugarcane, namely, the tops, bagasse and molasses are currently underutilised, even though they are a major potential source of energy. Bagasse and molasses contain residual sugars that are deemed uneconomical to remove, approximately 2% and 50% in bagasse and molasses, respectively, on a mass basis. According to the World Energy Council [46], bagasse constitutes about 20% of the weight of cane milled in the cane sugar industry, with an energy content of 2.85 GJ/tonne at 50% moisture content. Similarly, rice husk and straw are virtually unutilised and could serve as a major source of energy in Ghana.

In Ghana, traditionally, most of the agricultural crop residues are burnt on the farms to facilitate the harvesting process or as pest a control measure (e.g. cotton). Some of the residues are also used as a substitute for firewood. However, there is currently no information about the share of different utilisations. It is noted that in practice, not all the existing agricultural residues can be collected and used for bioenergy production due to technical constraints, ecosystem functions, and other uses (e.g. animal fodder, fertiliser, domestic heating and cooking). Clearly, collection of all the residues could adversely affect soil fertility [38]. Currently, many of the agricultural [35] residues mentioned in this review are scarcely utilised. Of all the agricultural crops grown in Ghana, maize seems to generate more residues than any other crop. Like other wastes, agricultural residues are lignocellulosic biomass, and therefore, contain a high amount of organic constituents (i.e. cellulose, hemicellulose and lignin) and a high-energy content. Therefore, they can be recognised as a potential source of renewable energy based on benefits of energy recovery and environmental protection [19].

The proximate composition of some major crop residues available in Ghana is presented in Table 9 [37]. Generally, the chemical composition of a crop residue varies as a result of factors such as variety, age of residue or stage of harvest, physical composition including, length of storage, and harvesting practices. The residue-to-product ratios (RPRs) of the various crops also vary depending on various factors including crop variety, water and nutrient supply, and the use of chemical growth regulators. The relative proportions of the various constituents determine the suitability of the residues as a potential biofuel feedstock [19].

2.3. Forestry resources

2.3.1. Forest biomass

Ghana's forest is a major source of biomass that could contribute considerably to the country's biofuel potential. The FAO [9] estimated that in 2006 the total forest area covered roughly 5.52 million ha, approximately 24.3% of the total land area [Table 10]. The forest area per inhabitant was also estimated at 0.24 ha. In 2006, the forestry sector contributed approximately 0.4% to the total labour force and about 7.2% to the country's GDP. The gross value added (GVA) from round wood production represented US$542 million, while the GVA of the total forestry sector accounted for US$754 million. Round wood extraction accounted for 1.30 million m^3.

Table 10
Forest resources in Ghana 2005 [9].

	Unit	Value
Forest area	1000 ha	5,517
% of land area	%	24.3
Area per 1000 people	Ha	240
Annual change rate		
1990–2000	1000 ha	-135
	%	-2
2000–2005	1000 ha	-115
	%	-2.0
Woody biomass	(tonne/ha)	180
Woody biomass	Tonne (million tonnes)	993

It is estimated that the total growing stock, and biomass in the country's forests was 321 million m^3, and 993 million tonnes, respectively. The forest plantations in both private and public ownership covered approximately 76,000 ha in 2000. About 40,000 ha of the plantations were covered by *Tectona grandis*, while the rest were other hardwoods [47]. Recently, the government re-launched the National Forest Plantation Development Programme which seeks to regenerate about 400,000 ha of both degraded reserves and off-reserve areas. Almost all the forest land in Ghana is vested in local communities, and open to traditional activities, including collection of non-timber forest products, hunting, and fuelwood collection [10]. Timber extraction in both the off-reserve and forest areas are regulated by an annual allowable cut (AAC) of 1.5 and 0.5 million m^3, respectively, giving a total AAC of 2.0 million m^3 [50]. Currently, timber resource allocation is conducted through competitive bidding aimed to ensure an efficient allocation of the resource. According to the FAO, forest losses between 1990 and 2000, and 2000 and 2005 were 135,000 and 115,000 ha, respectively. The high rate of deforestation has been attributed to various factors such as excessive logging, unsustainable agricultural practices, bush burning, mining, quarrying, settlement, population growth and migration, especially in the forest areas. Table 11 shows production and use of woodfuel, industrial round wood, sawnwood and wood-based panels in 2008.

2.3.2. Forest residues

According to the FAO [9], the annual global use of wood is approximately 4×10^6 m^3. It is estimated that approximately 55% of this volume is utilised as fuelwood, mainly in developing countries. The remaining 45% is used as industrial raw material [50]. The

Table 9
Proximate composition of major agricultural crop residues generated in Ghana [37].

Crop residue	% Dry matter						
	Moisture (%)	Crude protein	Organic matter	Crude fibre	Ether extract	Ash	NFE[a]
Maize stover	10	2–8	85–91	28–46	1–2	9–15	35–53
Sorghum stover	10	3–6	96	31–35	1–2	4	50–56
Rice straw	10	2–9	75–90	20–45	1–4	10–25	29–48
Groundnut haulms	10–12	11–17	87–90	21–29	1.5–2.5	10–13	51–57
Cowpea vines	10–12	6–18	82–90	25–30	1–1.5	8–10	48–50
Cassava tops	70–80	17–27	89–94	8–26	3–8	6–11	35–60
Sweet potato tops	90	20–22	82–83	15	3–3.5	17–18	42–46
Sugarcane tops	70–80	5–8	81–95	28–34	1.5–2.5	5–9	44–54
Cocoa pods	75	2–9	75–90	20–45	1–4	10–25	33–56
Empty oil palm fruit bunch	56	3–4	95	-	6–8	5	–

[a] NFE = nitrogen fee extractives.

Table 11
Production and consumption of woodfuel, industrial round wood, sawn wood and wood-based panels, 2008 [9].

Product	Production ($10^3\,m^3$)	Consumption ($10^3\,m^3$)
Wood fuel	33,040	33,040
Industrial round wood	1,304	1,305
Sawn wood	527	317
Wood pulp	0	0
Wood based panels	335	161
Paper and paper board	0	0

residues generated from the forest products industry could be divided into two categories: (i) logging residues, generated from logging activities and industrial by-products (i.e. wood processing wastes) generated by wood processing firms during the manufacture of sawn wood, plywood, particleboard, etc. [Table 12].

- Logging residues

  Logging residues include stumps, off-cuts, saw dust, etc. [Table 12]. A study conducted by Amoah and Becker [51] on commercial logging efficiency in Ghana showed an average logging recovery of 75%. Similar to agricultural crop residues, in practice, not all of the logging residues can be used for bioenergy production due to technical constraints, ecosystem functions, and other uses such as animal fodder and fertiliser. There are also environmental concerns considering an extensive long term use of logging residues. For instance, leaving appropriate levels of logging residues protects soil quality and eliminates the need for the use of fertilisers [19,50]. Logging residues generated in 2008 are estimated at 720,000 m^3, equivalent to 360,000 tonnes based on 2008 production data for industrial round wood, and RPR of 0.6. The moisture content of the wood residues and the weight of 1 m^3 solid roundwood were assumed to be 50% and 0.5 tonnes, respectively.
- Wood processing wastes

  Wood processing wastes such as discarded logs, bark, sawdust, off-cuts, etc., on the other hand, are generated through sawmill and plywood mill processing activities [Table 12]. It is reported that, generally, sawmills in Ghana have recovery rates ranging from 20% to 40% of the log input, averaging 33.3% [53]. A World Bank report on Sector Reform and the Pattern of the Poor—energy use and supply indicated that sawmill residues are among the most promising feedstock for energy purposes in Ghana. Another report by UNDP/World Bank Energy Sector Management Assistance Project on Sawmill Residue Utilisation in 1988 indicated that solids and sawdust accounted for 79% and 21%, respectively, of the residues generated [49]. It is estimated that wood processing wastes generated in 2008 totalled 256,000 m^3, equivalent to 128,250 tonnes, based on sawn wood production for 2008 and RPR for solid wood and moisture content sourced from the FAO Statistics [22], and RPR, moisture content and weight of solid wood sourced from the OECD/IEA [19], respectively. According to the OECD/IEA [19], the use of wood processing wastes as feedstocks for second-generation biofuels would be attractive since they are normally concentrated at the various mills, and their collection would not be complicated or costly. In Ghana, it is reported that over 50% of the industrial wood waste is utilised off-site, either as firewood or converted into charcoal using earth mound kilns [49].

Table 12
Sources and types of forest residues.

Source of residue	Type of residue
Forest operations	Branches, stump, roots, low-grade and decayed wood, slashings and sawdust
Sawmilling and planning	Bark, sawdust, trimmings, split wood, planer shavings
Plywood production	Bark, core, sawdust, veneer clippings and waste, panel trim, sander dust
Particleboard production	Bark, screening fines, panel trim, sawdust, sander dust

2.4. Urban wastes and other wastes

Urban wastes are generated by people during their daily activities. With increasing urbanisation in the country, there is heightened environmental awareness on both the generation and disposal of urban wastes. In Ghana, urban wastes can be categorised into four major types, namely municipal solid waste (MSW), sewage sludge, food waste, and fat, oil and grease (FOG). The availability of the various types of urban wastes is discussed in the subsections.

2.4.1. Municipal solid waste

Municipal solid waste (MSW) is generated by households, commercial and industrial sectors as a result of the concentration of population, and activities in urban areas. It is estimated that approximately 760,000 tonnes of MSW annually or approximately 2,000 tonnes per day is generated in Accra, the capital. According to Kramer et al. [54], the generation of MSW in Accra typically shows a daily per capita generation rate and density of 0.40 kg and 0.47 tonnes m^{-3}, respectively. In Kumasi, the second largest city, waste generation is about 0.6 kg/person per day. Generally, the organic content of MSW constitutes about 68%, indicating its high potential as a source of energy (Fig. 2). In Ghana, three sanitary landfill projects are reported to have been commissioned between 2003 and 2004. These are located in Accra, Kumasi, Sekondi-Takoradi and Tamale. The landfill waste materials are decomposed by anaerobic bacteria to produce landfill gas which typically consists of 50% methane and 50% carbon dioxide [55–58].

2.4.2. Food industry wastes

Large quantities of both solid and liquid food wastes are generated by the food industry, hotels, restaurant and confectionary industry in the country. They include foods that do not meet specified quality control standards, peelings and scraps from crops, fruits and vegetables. Most of the solid food wastes normally enter the waste dumps. Waste waters from the food industry contain sugars, starches, and other dissolved and solid organic matter. In considering food wastes as biofuel feedstock in the country, it is important to note that their chemical composition and nutrient content vary with the type of food item. In Ghana, potential exists for these food wastes to be digested using anaerobic process to produce biogas, or fermented to produce ethanol in view of the large size of the food industry [3].

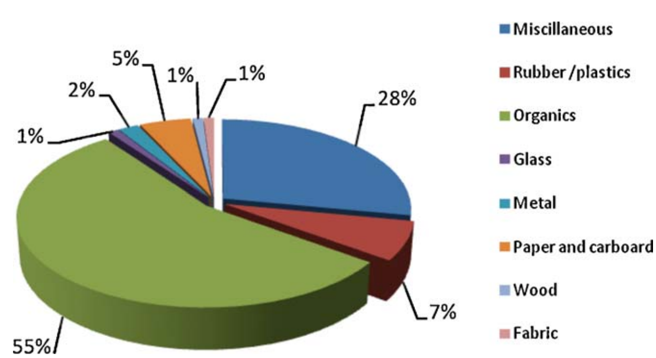

Fig. 2. Composition of household waste in Kumasi [55].

Table 13
Livestock population in Ghana, 2001–2008 (10^3) [22].

Year	2001	2002	2003	2004	2005	2006	2007	2008
Cattle	1,315	1,330	1,344	1,365	1,385	1,406	1,427	1,427
Goats	3,199	3,230	3,560	3,595	3,632	3,668	3,704	3,704
Pigs	312	310	303	300	305	229	239	239
Sheep	2,771	2,922	3,015	3,112	3,211	3,314	3,420	3,420
Poultry	22,032	24,251	26,395	29,500	30,000	30,500	31,000	31,000

2.4.3. Industrial wastewater/sewage sludge/bio-solids

Sewage is a source of biomass energy that is very similar to animal wastes. Energy can be extracted from it using anaerobic digestion to produce biogas. Generally, industrial wastewater treatment in Ghana is minimal. Since most of the industrial activities in the country are sited along the coast such as Tema, Accra and Takoradi, they dispose of their wastewaters directly into the sea. It is reported that only a few industries and abattoirs carry out some primary industrial wastewater treatment by employing either on-site or off-site disposal methods. These facilities are located in various parts of the country such as Kumasi, Tema Community Three, the University of Ghana Staff Village, and the Burma Camp. They can also be found at the Nsawam Maximum Security Prison, the Kwame Nkrumah University of Science and Technology, Kumasi, the La Palm Royal Beach Hotel, Golden Tulip, and the 37 Military Hospital in Accra [54–57].

2.4.4. Animal wastes

Livestock manure refers to animal garbage. The quantity of manure produced generally depends on the amount of fodder eaten, the quality of fodder, and the live weight of the animal. The most domesticated livestock populations in Ghana are cattle, pig, sheep and poultry [Table 13]. It is estimated that a cow normally produces about 16 tonnes of manure (wet weight) per year, giving an annual cattle wet manure resource of about 22.8 million tonnes in 2008 [59]. At a moisture content of 87.3%, this translates to a total dry weight of approximately 2.9 million tonnes [21,60,61]. About 76% of the cattle in Ghana are located in the Upper East, Upper West, and Northern Regions, and are free-roaming, usually kraaled at night [49]. Although the majority of rural households in these areas keep some sort of livestock, livestock farming is adjunct to crop farming. In the southern part of the country, poultry keeping predominates. However, sheep and goat production is generally widespread throughout the country [60].

2.4.5. Fat, oil, and grease

Fat, oil and grease (FOG) or urban grease waste are generated as by-products from food preparation activities. These wastes can be classified into two categories, namely yellow grease and grease trap waste [59]. Information on the availability and potential use of FOG as an energy source in the country is currently not available.

3. Biofuels potential in Ghana

Recent surges in global fossil oil prices, and concerns about energy and climate change from greenhouse gas (GHG) emissions have prompted both developed and developing countries alike to pursue course for biofuels production. Many sub-Saharan African countries see biofuels also as a way to stimulate rural development, create jobs, and save some foreign exchange. To date, the transport sector has been the key area for large-scale efforts in biofuel use worldwide. The two primary biofuels consumed are ethanol and biodiesel.

Currently, the United States and Brazil, which make ethanol from maize and sugarcane, respectively, are the world's two largest biofuel markets. In Africa in general and Ghana in particular, there are prospects of bilateral or multilateral aid transfer for climate change mitigation through the development of biofuels. Ghana, for instance, could sell part of her carbon credits to countries with high reduction commitments under the Clean Mechanism component of the Kyoto Protocol [5] and also take advantage of biofuel production to increase the consumption of modern energy [5,60]. In Ghana, a large scope exists for the exploitation of different types of biomass, such as energy crops, agricultural and forestry residues, wood processing wastes, and municipal solid waste for conversion to biofuels using different routes. Thus, biomass conversion to energy and fuels may be rewarding in the country given the large availability of all these biomass resources [60]. The subsections briefly describe biomass conversion technologies that have been applied or tested in the country over the past years.

3.1. Biomass conversion technologies tested in Ghana

3.1.1. Chemical transformation

The production and use of liquid biofuels as alternative fuels to fossil fuel is a recent phenomenon in Ghana. Generally, the main interest has been on biodiesel derived from jatropha, palm oil and soybean. Some initiatives on biofuel development have already been taken by the government, the private sector, non-governmental organisations (NGOs), and the UNDP [4].

3.1.2. Biochemical conversion—anaerobic digestion

It is estimated that approximately 129,200 tonnes of organic matter is available in the MSW generated annually in Accra. These waste materials could be potential feedstock for biofuel production. In Ghana, over 240 digesters with capacities ranging from 6 to 10 m^3 have been installed. Under a Bio-sanitation programme, the Institute of Industrial Research of the Council for Scientific and Industrial Research of (CSIR-IIR) has installed several biogas systems for various schools, prisons, hospitals and district assemblies. It has also promoted the utilisation of the solid residue as a natural fertiliser. Biogas has also been utilised to fuel a combustion engine to generate electricity at Appolonia, a rural community, as a demonstration project of the Ministry of Mines and Energy under the Renewable Energy Programme [4,60].

3.1.3. Thermal conversion processes

Pyrolysis is the thermal degradation of organic matter in the absence of oxygen, and occurs at a temperature range of 400–800 °C. The primary pyrolysis products of biomass are usually referred to as condensable (tars) and non-condensable volatiles, and char. The condensable volatiles (tars) are often classified as liquids (bio-oil), and non-condensable volatiles are gases mainly, CO, CO_2, H_2 and C_1–C_2 hydrocarbons [58–62]. Basically, pyrolysis can be categorised into conventional, slow, and fast or flash pyrolysis. Conventional pyrolysis, which occurs under a slow heating rate, has been employed for the production of charcoal [48]. In flash or fast pyrolysis, processing conditions include: (1) a very high heating rate and heat transfer rate, (2) finely ground biomass feed (<1 mm), and (3) rapid cooling of the pyrolysis vapours to give the bio-crude products [1]. Fast pyrolysis is associated with tar, at temperature range of 675–775 K, and/or gas. Slow pyrolysis of biomass, on the other hand, is associated with a high charcoal content [61–65].

It is estimated that approximately 976,000 m^3 of forestry residues were generated in the country in 2008. Assuming a 25% availability of these residues, this would imply that approximately 244,000 m^3 of forestry residues, amounting to 122,000 tonnes were available for bioenergy production that year. Biomass fast pyrolysis could thus be an attractive option because of the abundant biomass resources in the country. These could be converted into crude bio-oil and used for both transport and combustion. The resulting by-product, called biochar, could be used for agronomic or horticultural purposes such as soil amendment. Biochar has been shown to increase soil fertility by improving nutrient and water retention. It also lowers soil acidity and density, and further increases microbial activity [3].

In Ghana, only a single pyrolysis project has been reported. This project was implemented jointly by the Building and Road Research Institute, the Technology Consultancy Centre of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi and Georgia University of Technology, USA. It aimed to determine the feasibility of using pyrolysis as an alternative process for power generation. The pyrolysis plant, which had a capacity of 6 tonnes, utilised sawdust as feedstock to provide an alternative fuel for a brick kiln. Char and oil yields were projected at 25% and 18%, respectively. Unfortunately, the plant had to be shut down following low yields which ranged between 6% and 13% that were obtained, in addition to poor supply and drying of feedstock and utilisation of manual process controls [48]. Recently, the CSIR-IIR has teamed up with the University of Southampton in the UK to construct a pilot pyrolysis plant for bio-oil production using agricultural crop residues and wood processing wastes in Ghana.

In gasification, biomass is partially oxidized by controlling oxygen to produce combustible gases. The resulting gas, commonly called syngas, contains hydrogen (18–20%), carbon monoxide (18–20%), carbon dioxide (8–10%), methane (2–3%), trace amounts of higher hydrocarbons such as ethane and ethene, water, nitrogen, and various contaminants such as small char particles, ash, tars and oils. This could be fed into a combined cycle gas turbine power plant. Gasification occurs at temperatures around 800 °C. In Ghana, biomass gasification has only been limited at research and development stage and evaluation of plants [4]. A few feasibility studies have also been conducted on the potential for cogeneration from wood residues. These include feasibility study on Letus Power Plant, and case study on the potential for co-generation from wood residues in three cities in Ghana [48].

A co-generation plant with approximately 6 MW capacity has been installed using sawmill and oil palm wastes as feedstock. This plant serves as the source of electric power for some industries and surrounding communities without grid electricity. There is high potential for co-generation in Ghana, but this potential is hindered by factors including the availability of cheaper power supply from grid electricity, lack of financial or fiscal incentives, and lack of regulatory requirements that would encourage investors to generate and sell electricity to the grid [4]. Currently, a few industries use co-generation, including the SAMATEX Ltd. located at Samreboi in the Western region, and STP in Kumasi.

3.2. National policy target for biofuels development

A number of African countries, including South Africa, Nigeria and Ethiopia have already adopted a National Biofuels Policy. In South Africa, three large biodiesel plants with a total annual production capacity exceeding 300 million litres have been planned. Furthermore, a Biofuels Industrial Strategy which stipulates a blending ratio of 2% of biodiesel, and 8% of ethanol has been adopted. It is expected that biofuels development would create about 25,000 jobs in the country. Proposed crops as biofuel feedstocks are sugarcane and sugar beet for ethanol production, and sunflower, rapeseed and soya for biodiesel. Maize and Jatropha, however, have been excluded as feedstocks [66].

In Ethiopia, about 8 million l of bioethanol is produced annually using molasses as feedstock. The country is also aiming to blend 5% ethanol into its gasoline pipeline. A UNDP project in the country is investigating the feasibility of utilising ethanol for domestic purposes such as cooking and heating. Altogether, the Ethiopian government plans to commit approximately 24 million ha of land to jatropha cultivation [66]. In Nigeria, ethanol production has been going on since 1973 using cassava as the main feedstock. Already, the government has adopted a 10% blending policy. One of the major biofuel companies in the country, the Nigeria Yeast & Alcohol Manufacturing Company plans to establish a US$200 million ethanol plant, with an annual production target of 30 million l.

In Mali, the Mali Folk Centre has over the years been developed energy service centres using 20-ha jatropha plantations to provide local energy for activities such as millet grinding and battery charging using multi-functional platforms (MFPs). Furthermore, a 15-year programme, which aims to utilise about 1000 ha of *Jatropha curcas* plantations to provide power to approximately 10,000 residents, is also being implemented. Also, in Kenya, the Agro Chemical and Food Cooperation is currently producing approximately 60,000 l per day of industrial ethanol, which is sold domestically and also exported to Uganda, Rwanda and Central Africa [66].

In Ghana, the government has already given approval to the ScanFuel Company Limited to commence the production of biodiesel in 2009, using jatropha oil to be produced from about 400,000 ha of land. A Draft National Biofuel Policy (NBP) on the production and use of biofuels in Ghana has since 2005, been prepared, and submitted to Parliament to be enacted into legislation. The National Biofuel Policy, which aims to accelerate the development of the biofuel industry in the country focuses on biodiesel production using jatropha oil. It also recommends the replacement of 5% of petroleum diesel with biodiesel by the year 2010, and 20% by the year 2015 [4]. Apart from defining the strategic objectives for biofuels development, the biofuel policy also makes recommendations on infrastructure development, institutional framework, regulatory framework including licensing, quality of product and fiscal incentives to attract investments.

With regard to research and development (R&D) on biomass and biofuels development, the policy recommends that the country's research institutions and universities conduct re R&D with the objective to improve the efficiency of biofuels production technologies so as to reduce production costs, raise the quality and efficacy of the products, and enable the country Generally, the biofuel industry in Ghana is expected to: (i) reduce the country's dependence on oil imports to enable some foreign exchange to be conserved, (ii) improve energy diversification and security in the county, (iii) create rural employment to reduce rural poverty, and (iv) create a market for agricultural produce as a source of income by selling carbon credits under the Kyoto protocol. Already, national standards for biofuels, together with a permitting framework and a National Road Map for introducing biofuels into the petroleum sub-sector have been developed [4].

3.3. Research gaps and next steps

Various R&D activities on biomass resource and biofuels development in Ghana have over the past years been focused primarily on the development of first-generation biofuels, particularly biodiesel and bioethanol, together with analyses of various biofuel feedstocks. Among the major institutions that have been engaged in these R&D activities are the Institute of Industrial

Table 14
Biofuel research and development initiatives in Ghana.

Research institutions/Universities	Research and Development Topics
CSIR-Institute of Industrial Research (CSIR-IIR), Accra	Second-generation technologies development. Biogas technology, Laboratory studies on biofuels.
CSIR-Forestry Research Institute of Ghana (CSIR-FORIG)	Development of improved *Jatropha curcas* plant and seed production: collection and handling, and viability testing.
CSIR-Savannah Agricultural Research Institute (CSIR-SARI)	Development &control of improved sweet sorghum species.
CSIR-Crops Research Institute (CSIR-CRI)	Improved maize species development.
Faculty of Renewable Natural Resources, CARN, KNUST, Kumasi	Development of second-generation technologies.
Dept. of Mechanical, Chemical Agricultural Engineering, KNUST, Kumasi	Plant design and fabrication; laboratory testing; trans-esterification of local feedstock.
University of Ghana, Legon.	Behavior of *Jatropha curcas* plant under different agro-ecological zones.
University for Development Studies, Tamale	Jatropha plant improvement.
University of Cape Coast	Screening of plant species for the production of biodiesel.
Biotechnology and Nuclear Agricultural Research Institute	Plant tissue culture, sugar cane research.

Research of the Council for Scientific and Industrial Research (CSIR-IIR) and the KNUST, Kumasi [Table 14]. Recently, the CSIR-IIR co-hosted an international workshop on Biofuels: R&D and Technologies for a sustainable development in Ghana, in collaboration with the International Centre for Science and High Technology (ICS-UNIDO) based in Trieste, Italy. This event has paved the way for various R&D activities on the development of the second-generation biofuel technologies in the country. Currently, the CSIR-IIR is implementing a joint UK-CSIR-IIR project on the development of the second-generation biofuels, with a focus on biomass fast pyrolysis with the University of Southampton, UK.

Based on the results of the review, some R&D gaps have been identified which require to be addressed in order to enable Ghanaian scientists and other stakeholders in the biofuel industry to better understand current and future availability of biomass resources, and also biofuels production and utilisation potential in Ghana. These include inadequate knowledge of the resource base, and biofuel technologies, particularly the second-generation biofuels technologies. Other gaps are knowledge of the national distribution of feedstock and issues relating to sustainability and greenhouse gases (GHGs) impacts as a result of both feedstock and biofuel production. In the meantime, it is relevant to focus biomass resources and conversion technologies R&D activities on: (i) biomass feedstock assessment, (ii) the characterisation of potential biomass feedstock for second-generation biofuels production, (iii) data collection on agricultural and forestry biomass, (iv) the development of second-generation biofuels technologies particularly, bio-chemical and thermo-chemical routes, including fast pyrolysis, (v) biomass process and kinetic modelling, (vi) the establishment of pilot and demonstration plants, (vii) the development of supply chain concepts, (viii) analysis of production costs, and (ix) the use of bio-technology to develop new feedstock varieties for biofuels production. It should be possible to develop models to integrate agriculture, forestry and biofuel markets, and to analyse GHG implications of changes in the various biofuel programmes, policies and market conditions.

4. Sustainability

In both developed and developing countries, fossil fuel price fluctuations and climate change are drivers to the increasing interest in biofuels. Most of the developed countries are moving from voluntary to obligatory legislations, resulting in an increase in the market share of biofuels in the transport sector. A number of African countries, including Ethiopia, South Africa and Egypt are, however, at the various stages of initiating large-scale biofuels production aimed to capture the benefits of its value chain. At the same time, an increasing numbers of African countries have also found themselves becoming potential suppliers of feedstock from the development of large scale plantations of energy crops driven by demand in the EU and the USA [66]. In Ghana, the local production and use of biomass resources as a substitute for fossil-based fuel offers many attractive benefits for the country. However, they could also have negative effects if not properly managed. Thus, socio-economic and environmental implications are required to be considered with the objective of forming the basis of addressing the potential impacts of biomass resource development, and also to guide appropriate national policies and strategies development.

4.1. Socio-economic implications

The current global interest in biomass resource and biofuel production, especially in the area of transportation fuels, presents an opportunity for both domestic and foreign investment in Ghana as well as increased export earnings. In Ghana, biomass has a varied effect: it would boost agricultural development and technological advancement, and further bring opportunities, thereby improving the quality of life. Also, because biomass resources can be converted to liquid and gaseous fuels, electricity and process heat, they can increase access to modern forms of energy for the population. Moreover, producing biomass resources locally reduces the country's dependence on foreign energy sources, and vulnerability to supply disruptions. Biomass resource cultivation, harvesting, and processing could have a direct impact on rural development. Biomass and biofuels production could improve rural livelihoods by providing new income opportunities to their families [19]. However, biomass production should not be made to affect food security in the country. It should rather positively contribute to increasing the productivity of food crops cultivated by the farmers producing the bioenergy crops. Efforts should be made to avoid human health impacts and risks through regular training and awareness on the impacts of biofuel production and use [67].

4.2. Environmental impact

Potential environmental benefits to be derived from the local production and use of biomass resources and biofuel production include offsetting GHG emissions associated with burning fossil fuels, waste utilisation, and erosion control. Clearly, biomass technology may benefit the environment while at the same time it may help solve some pressing environmental problems. It is reported that using biomass to produce energy is carbon-neutral because it releases roughly as much carbon dioxide (CO_2) as it takes in. For instance, for every MWh of power generated using biomass, approximately 1.6 tonnes of CO_2 are avoided. Also, the use of biomass resources, managed in a sustainable way, could reduce CO_2 emissions and thus help tackle global warming [19]. Methane, the principal component in biogas, is produced by anaerobic digestion or fermentation of biodegradable materials such as manure. It is also one of the potent GHGs. According to the

IPCC (Intergovernmental Panel on Climate Change), methane is about 21 times as effective as CO_2 at trapping heat in the atmosphere. Therefore, reducing 1 tonne of methane has the same positive effect as reducing 21 tonnes of CO_2. The use of MSW, which is abundant in Ghana, as an energy source could provide two important benefits, namely environmentally safe waste management and disposal, as well as clean electric power generation [19].

Negative environmental impacts associated with the production and use of biomass resources include inappropriate land use (deforestation), land availability, land use-conflicts, increased GHG emission, loss of biodiversity, and soil erosion. Since majority of Ghana's population relies almost entirely on biomass resources for their energy needs, using alternative sources of energy is seen to be crucial to forest sustainability. The planting of energy crops, for instance, could increase vegetation coverage, and substantially improve the local environment such as reduction of soil erosion. But, extensive use of tillage, fertilisers and irrigation could lead to the deterioration of the physical and chemical properties of soil, such as reduced soil fertility, accumulation of toxic substances, and reduced organic matter. Residues left on the farms improve the soil by returning the nutrients, and also inhibit weed growth. The development of cellulosic ethanol and pyrolysis oil, however, may cause some of the farmers to remove huge amounts of agricultural crop residues for sale in order to increase their income to the detriment of the soil [19].

5. Conclusions

This review critically focuses on biomass resources currently available in Ghana, and the potential to utilise them for the production of various types of biofuel. The review shows that a variety of biomass resources exists in the country, and that there is also an immense opportunity for their conversion to various types of biofuels using different biomass conversion technologies that are currently available. The availability of different types of agricultural crop residues, forest residues and wood processing wastes in Ghana makes them potential biofuel feedstocks, particularly for the production of the second-generation biofuels. Also, the organic portion of MSW, together with animal manure could play a major role as potential feedstocks for the production of biogas.

However, there are currently a lot of both public and environmental concerns with respect to biofuel development in Ghana. Therefore, any decision to select a particular energy source for national biofuel development would depend on factors such as technical, economic, social and environmental benefits that would be derived from the implementation of such schemes. Therefore, such schemes should not be implemented in haste, but rather should first proceed cautiously in the form of pilot schemes, which may then be transformed into large-scale schemes.

References

[1] Kersten SRA, Wang X, Prins W, van Swaaij WP. Biomass pyrolysis in a fluidized reactor. Part 1. Literature review and model simulations. Industrial and Engineering Chemistry Research 2005;44(23):8773–85.
[2] Bridgwater AV, Meier D, Radlein D. An overview of pyrolysis of biomass. Organic Geochemistry 1999;30(12):1479–93.
[3] Singh J, Gu S. Biomass conversion to energy in India—a critique. Renewable and Sustainable Energy Reviews 2010;14(5):1367–78.
[4] Ahiataku-Togobo W, Ofosu-Ahenkorah A. Bioenergy policy implementation in Ghana. In: COMPETE international conference; 2009, http://www.compete-bioafrica.net.
[5] Energy Sector Management Assistance Programme, Ghana: Sector reform and the pattern of the poor. Energy use and supply. ESMAP Technical Paper 097/06, March; 2006. http://www.esmap.org/filez/.
[6] IEA. Energy statistics—electricity for Ghana 2007. International Energy Agency; 2007, http://www.iea.org/stats/electricitydata.asp.
[7] Gand EK. Country profile for Ghana, Sustainable energy technology at work, October; 2009. http://www.setatwork.eu/downloads/SETatWork_Ghana_Profile_0910.
[8] USDA. Assessment of local production for school feeding in Ghana, June 1–2, 2009. USAD Foreign Agricultural Service Office of Capacity Building and Development; 2009, http://www.signschoolfeeding.org/.
[9] FAO. State of the World's forests. Rome, Italy: Food and Agriculture Organisation of the UN; 2009.
[10] World Trade Organisation, Trade policy review Report by the secretariat. WT/TPR/S/194, December; 2007. http://www.wto.org/english/tratop_e/tpr_e/s194-00_e.doc.
[11] Ghana Economy 2010, CIA World Fact book. http://www.theodora.com/wfbcurrent/ghana/ghana_economy.html.
[12] UNDP. Human development reports, Ghana: Economic challenges, January; 2009. http://hdr.undp.org/en/nhdr/monitoring/news/2009/title,16525,en.html.
[13] UNDP. Human settlement country profile—Ghana; 2003, http://www.un.org/esa/agenda21/natlinfo/countr/ghana/hsettlementghana04f.pdf.
[14] Knudson B. State of the art of solar cooking: a global survey of practices and promotion programmes. Solar Household Energy Inc. Solar cooking for human development and environmental relief. http://www.she-inc.org/art.php?id=36.
[15] NREL. Assessment of biomass resources in Liberia. Technical report, NREL/TP-6A2-44808, April; 2009.
[16] Demirbas A. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Conversion and Management 2001;42:1357–78.
[17] Roewell RM. The chemistry of solid wood. Washington, DC: American Chemical Society; 1984.
[18] FAO. Planted forests and second-generation biofuels, planted forests and trees. Working paper 42E. Rome, Italy: Forest Resources Development Service, Food and Agriculture Organisation.
[19] OECD/IEA. Sustainable production of second-generation biofuels, potential and perspectives in major economies and developing countries, Information paper. February; 2010. http://www.iea.org/papers/2010/second_generation_biofuels.pdf.
[20] Statistics, research information directorate (SRID). Agriculture in Ghana. Facts and figures. Accra: Ministry of Food and Agriculture; 2007.
[21] Wetlands International, Biofuels in Africa. An assessment of risks and benefits for African wetlands, AID Environment, May; 2008. http://www.unido.org/fileadmin/user_media/UNIDO_Header_Site/Subsites/Green_Industry_Asia_Conference__Maanila_/GC13/Wetlands.pdf.
[22] FAOSTAT. Crop production Ghana, 2008. Rome, Italy: Food and Agriculture Organisation of the UN; 2008, http://faostat.fao.org/site/567/default.aspx.
[23] Technoserve. Study of biofuel production in Ghana: assessing competitiveness and structure of the industry's value chain. Final report. May 2nd; 2007. http://www.gwu.edu/~elliott/assets/docs/acad/ids/capstone/ghana07.pdf.
[24] Hagan EB. Biomass assessment report—ECOWAS sub-region. In: AU/Brazil/UNIDO Biofuels Seminar in Africa; 2007.
[25] Garwe EC, Jingura RM, Chateya SR, Musademba D, Simbi DJ. New approaches to the sustainable development of the biofuels industry in Zimbabwe: propagation of *Jatropha curcas* for oil extraction and biodiesel production. Workshop paper. ICS-UNIDO/CSIR International workshop on biofuels in Ghana; 2007. http://www.ics.trieste.it/media/138276/df5113.pdf.
[26] Schoneveld GC, German LA, Nutakor E. Paper summary—towards sustainable biofuel development: assessing the local impacts of large-scale foreign land acquisitions in Ghana. In: World Bank land governance conference; 2010, http://siteresources.worldbank.org/EXTARD/Resources/336681-a.1236436879081/5893311-1271205116054/schoneveld.pdf.
[27] Gyasi EA. Emergence of a new oil palm belt in Ghana. Royal Dutch Society 2008;83(1):39–49.
[28] Dery SK, Philippe R, Baudouin L, Quaicoe RN, Nkansah-Poku J, Owusu-Nipah JJ, et al. Dare D, Dollet M. Coconut in Ghana. Journal Euphytica 2008;164(1):1–11.
[29] Nkansah PJ, Philippe R, Quaicoe RN, Dery SK, Ransford A. Cape Saint Paul Wilt disease of coconut in Ghana: surveillance and management of disease spread OCL. Oléagineux Corps Gras Lipides 2009;16(2):111–5.
[30] Coconut revival—new possibilities for the 'tree of life'. Adkins SA, Foale M, Samosir YMS, editors. Proceedings of the International Coconut Forum, 2005, http://aciar.gov.au/system/files/node/748/PR125%20full%20text.pdf.
[31] UNDP supported Sunflower Bio-diesel production in Ghana to start in January 2009, United Nations Development Programme brief, Ghana; 2008.
[32] Dzobefia VP, Arthur PL, Zakpaa AD. Value addition to locally produced soybean in Ghana: production of soy sauce using starter culture fermentation. Journal of Science and Technology 2007;27(August (2)):23–7.
[33] Plahar WA. Overview of the soybean industry in Ghana. In: Workshop on soybean protein for human health, World initiative for soy in human health; 2006, http://www.wishh.org/workshops/intl/ghana/ghana06/plahar-06.pdf.
[34] Scurlock JMO. Mischanthus: a review of European experience with a novel energy crop. ORNL/TM-13732; 1999.
[35] Falkowski PG, Raven J. Aquatic photosynthesis. Oxford: Blackwell; 1907 , 375 pp.
[36] Nunoo FKE, Ameka GK. Occurrence of macro-algae in the by-catch of beach Seine fisheries at Sakumono, Ghana. West African Journal of Applied Ecology 2005;8:79–87.
[37] FAO. Utilisation of crop residues in the nutrition of sheep and goats in the humid tropics of West Africa. Food and Agriculture Organisation of the United Nations corporate document repository; 2010 , http://www.fao.org/docrep/004/s8374b/S8374b06.htm.
[38] Cooper CJ, Laing CA. A macro analysis of crop residue and animal wastes as a potential energy source in Africa. Journal of Energy in Southern Africa 2007;18(February (1)):10–9.

[39] CSAE. Fertile ground: boosting cocoa production among smallholders. Briefing paper. August; 2009. http://www.csae.ox.ac.uk/output/briefingpapers/pdfs/CSAE-briefingpaper-01-Ghanacocoa.pdf.
[40] Caria S, Dzene R, Opoku E, Teal F, Zeitlin A. Impacts of group-based microfinance in agriculture: evidence from Ghana's Coco, Abrabopa Association. In: Paper presented at the CSAE conference, March; 2009, http://www.csae.ox.ac.uk/conferences/2009-EDiA/papers/473-CariaTealZeitlin.pdf.
[41] The Statesman/African News Network. Ghana's cocoa more than doubles in eight years, July 06; 2008. http://www.africanagricultureblog.com/2008/07/ghana-cocoa-production-more-than.html.
[42] GBC News. Ghana cocoa production up 703,000 tonnes, Agriculture, October; 2009. http://www.modernghana.com/news/242453/1/ghana-cocoa-production-up-703000-tonnes.html.
[43] Cuvilas CA, Jirjis R, Lucas C. Energy situation in Mozambique: a review. Renewable and Sustainable Energy Reviews 2010;14(September (7)):2139–46.
[44] OTAL Coffee News. Ghana to host international coffee forum—17/11/09; 2009. http://www.otal.com/commodities/coffee.htm.
[45] OTAL, Coffee News. Ghana & Gabon obtain full ICO membership status—20/08/09; 2009. http://www.otal.com/commodities/coffee.htm.
[46] IEA. Survey of wood fuels. World Energy Council; 2001, http://www.worldenergy.org/documents/ser2004.pdf.
[47] Zhang D, Owiredu EA. Land tenure, market, and the establishment of forest plantations in Ghana. Forest Policy and Economics 2007;9(6):602–10.
[48] Atakora S-B. Biomass technologies in Ghana. In: The ninth biennial bioenergy conference 2000; 2000, http://www.nrbp.org/papers/046.pdf.
[49] Atakora S-B, Hagan EB, Brew-Hammond A. Providing power from sawmill residues in Ghana. A case study on Maxwell Owusu Timbers (MOW). http://www.nrbp.org/papers/039.pdf.
[50] Domson O, Vlosky RP. A strategic overview of the forest sector in Ghana. Louisiana Forest Products Development Center, Working Paper #81; 2007. https://www.lsuagcenter.com/NR/rdonlyres/10AF8836-05BA-4F7A-8AB9-E86C0B6EC792/53404/wp81.pdf.
[51] Parikka M. Global biomass fuel resources. Biomass and Bioenergy 2004;27:613–20.
[53] Sekyere D, Okyere PY. The potential of using wood residue for energy generation in Ghana. In: International conference on wood-based bioenergy; 2007, http://www.itto.int/direct/topics/topics.
[54] Kramer H, Jechimer K, Lengsfeld S, Nartey-Tokolli IB. Determination of major planning data for solid waste management in Accra metropolis. Accra, Ghana: Accra Metropolitan Assembly, Waste Management Department; 1994.
[55] Ketibuah E, Asase M, Yusif S, Mensah MY, Fischer K. Comparative analysis of household waste in the cities of Stuttgart and Kumasi—options for waste recycling and treatment in Kumasi. In: 19th international CODATA conference; 2005, http://www.codata.org/Ketibuah-ComparativeAnalysisofHouseholdWaste.htm.
[56] Owusu K, Kuitunen M. Municipal solid waste management in the Accra Metropolitan Area, Ghana. The Environmentalist 2003;23(3):211–8.
[57] Fobil JN, Carboo D, Armah AN. Evaluation of municipal solid wastes (MSW) for utilisation in energy production in developing countries. International Journal of Environmental Technology and Management 2005;5(1):76–86.
[58] Dotseh AE. Integration of municipal solid waste management in Accra (Ghana): bioreactor treatment technology as an integral part of the management process. MSc Thesis, Sweden: Lund University; 2004.
[59] FAO. Manures and agro-industrial by-products for fish farming in Ghana, Field working paper. Rome, Italy: Food and Agriculture Organisation of the UN. http://www.fao.org/docrep/field/003/ac111e/AC111E.
[60] Wilson I. Overview of the energy sector in the sub-region. In: Workshop on biomass technology for sustainable energy in Western Africa; 2009, http://kiteonline.net/docs/files/workshops/overview%20of%20energy%20sectorV02.pdf.
[61] Papadikis K, Gu S, Bridgwater AV, Gerhauser H. Application of CFD to model fast pyrolysis of biomass. Fuel Processing Technology 2009;90(4):504–12.
[62] Ganesh A, Banerjee R. Biomass pyrolysis for power generation a potential technology. Review Energy 2001;22(January–March (1–3)):9–14.
[63] Tsai WT, Lee MK, Chang YM. Fast pyrolysis of rice straw, sugarcane bagasse and coconut shell in an induction heating reactor. Journal of Analytical and Applied Pyrolysis 2006;76:230–7.
[64] Bain RL, Overend RP, Craig KR. Biomass-fired power generation. Fuel Processing Technology 1998;54:1–16.
[65] Zafar S. Biomass wastes, alternative energy. eMagazine, AltenergyMag.com, August/September; 2009.
[66] Gordon-Maclean. Situation analysis on biofuels industry in Tanzania. ESD Summary of report on biofuels in Tanzania. http://www.tnrf.org/E-INFO-WWF_Situation_Analysis_on_Biofuels_Industry_in_Tanzania_Andrew_Gordon-Maclean.pdf.
[67] Mohammed FA. Sustainable biofuels production and use with a focus on Africa. In: Eastern and Southern African regional workshop on biofuels; 2007, http://www.unep.org/urban_environment/PDFs/Fatin.